Int J Life Cycle Assess (2014) 19:1693–1704
DOI 10.1007/s11367-014-0775-5

CARBON FOOTPRINTING

Life cycle carbon footprint of the packaging and transport of New Zealand kiwifruit

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Received: 27 August 2013 / Accepted: 25 June 2014 / Published online: 9 July 2014

Abstract

Purpose The aim of this study is to assess the life cycle carbon footprint of the New Zealand kiwifruit packaging and transport supply chain to retailers in two major markets (Japan and Germany). Results of this study have been used to identify areas of the New Zealand kiwifruit packaging and transport supply chain that contribute significantly to the carbon footprint and to identify options for reduction.

Methods This study is based on the ISO standards for life cycle assessment (namely, ISO 14040:2006 and ISO 14044:2006). The PAS 2050 also provided further methodological guidance. Primary packaging data were sourced from Zespri's suppliers. End-of-life data were sourced from the market and waste statistics of the relevant countries. Gabi 4.4 was used for upstream material information and modelling.

Results and discussion The carbon footprint of the packaging and transport of kiwifruit ranged from 0.33 to 0.67 kg CO_2e per kilogram of fruit delivered to a store depending on pack type and market. Shipping accounted for the majority of these emissions (58–82 %), and Zespri is actively working with shipping companies to reduce this. There are also opportunities to reduce the carbon footprint through reducing the amount of fruit repacked in the market, using trains for long-distance transport and increasing packaging recycling rates.

Conclusions There is a range of options for reducing the carbon footprint of the New Zealand kiwifruit packaging and transport supply chain. These will tend to be incremental (i.e. a number of small gains) and would involve working closely with partners in the supply chain. Options include increased efficiency in shipping, use of trains for land transport, reductions in the addition of structural packaging in the market, managing the product mix to minimize those supply chains with a higher carbon footprint, identifying alternative material for components of the packaging, replacing the use of polystyrene clamshells with alternative materials or plastic bags and maximizing recycling rates along all stages of the supply chain.

Keywords Carbon footprint · Climate change · Greenhouse gas emissions · Life cycle · New Zealand kiwifruit packaging

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1 Introduction

Kiwifruit is New Zealand's second largest horticultural export, and Zespri is the largest global marketer of kiwifruit. The main markets are Europe and Japan, where NZ kiwifruit is supplied when kiwifruit is out of season locally. Mithraratne et al. (2010), in a scoping and methodology study of New Zealand kiwifruit, estimated the carbon footprint of 1 kg of fruit consumed in the UK at 1.61 kg CO_2e (1.55 kg CO_2e corrected for appropriate refrigerant losses based on McLaren et al. (2008)) but did not cover packaging in detail. Packaging is one area of the supply chain that Zespri has reasonable control over, so more information was needed for the informed assessment of options to reduce the carbon footprint of kiwifruit packaging from New Zealand.

The goals of the study were to quantify the life cycle carbon footprint of selected New Zealand kiwifruit packaging configurations and supply chains, identify any methodological issues and identify options to reduce the packaging carbon footprint.

The scope of the carbon footprint is cradle to grave (Fig. 1) and covers raw materials, packaging manufacture, secondary packaging (packaging required to facilitate transport of packaging to a kiwifruit packhouse), packaging transport to

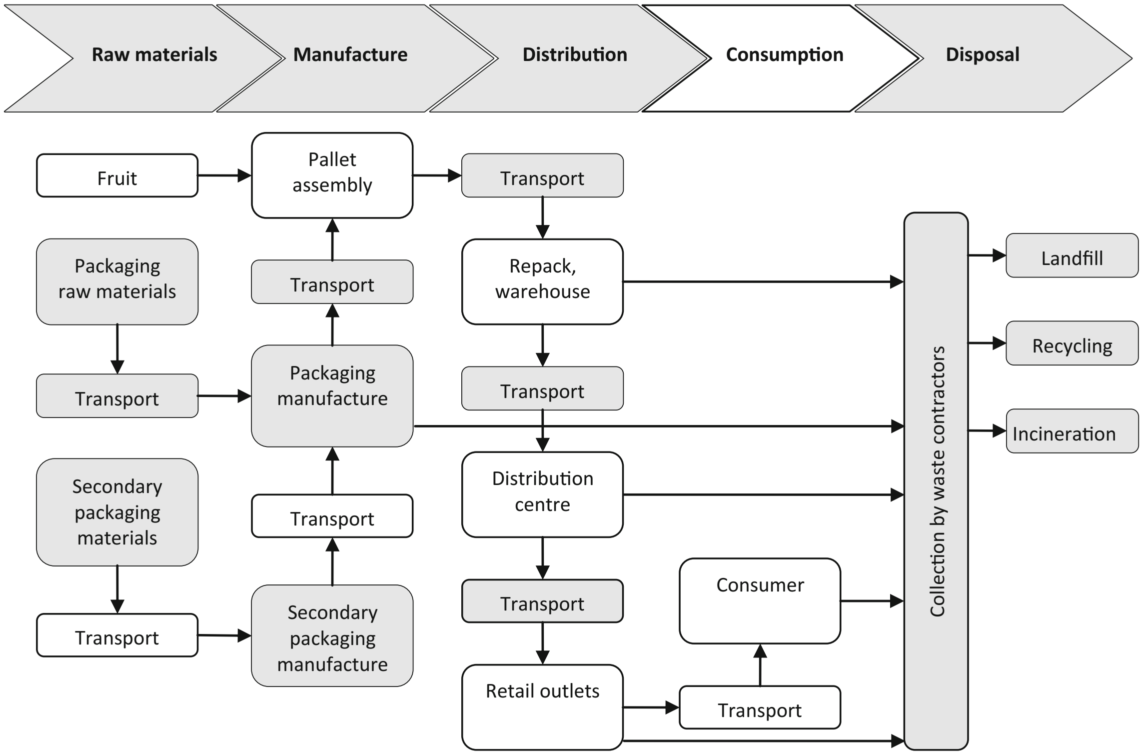

Fig. 1 Kiwifruit packaging carbon footprint study system boundaries

kiwifruit packing site, transport of fruit and its associated packaging to a retailer in Tokyo, Japan, and a supermarket in Munich, Germany, packaging transport to disposal site and end-of-life disposal. Japan and Germany were chosen as markets as they represent the largest of the New Zealand kiwifruit markets (33 % and 16 % of total exports, respectively, in 2010). The functional unit is the packaging and transport of 1 kg New Zealand kiwifruit to a retail outlet in Japan or Germany.

In Germany, green kiwifruit make up the majority of the kiwifruit exported from New Zealand (80 %). The supply chains analysed cover 88 % of the New Zealand green kiwifruit supplied to Germany and were

- modular bulk (MB) packs to retailer/supermarket (66 % of the green kiwifruit market), where kiwifruits are packed in bulk inside a plastic liner in a cardboard box and 100 boxes to a pallet.
- Plateau single (P1) to retailer/supermarket that originated from New Zealand as P1 (12 % of the green kiwifruit market). Each P1 cardboard box contains a plastic pocket pack in which fruits are individually packed, with a plastic liner around each pocket pack and 145 packs per pallet.
- P1 to retailer/supermarket that originated from a MB repacked at Zeebrugge (10 % of the green kiwifruit market). These are the same as the above P1 except that no plastic liner is used.

The Japanese supply chains analysed cover 82 % of the total New Zealand kiwifruit entering Japan, which were:

- International trays (IT) to the supermarkets (34 % of the market) and wholesale market (15 % of the market). Each IT contains a cardboard box with a plastic liner and a pocket pack in which individual fruits are placed with 232 boxes per pallet.
- Clamshells to the supermarkets that originated from a MB (21 % of the market). All MB packs are repacked either into clamshells containing four to six fruits or plastic bags.
- Plastic bags to the supermarkets that originated from a MB (12 % of the market).

Each pack type (MB, IT and P1) has a number of packaging components and these are listed in Table 1.

2 Methods

Product carbon footprinting is a methodology based on life cycle assessment (LCA). It is a technique for assessing the potential greenhouse gas emissions of products and services along their life cycle from the extraction of raw materials through refining, manufacturing, distribution and use to waste management. While this is a carbon footprint study, it is guided by two LCA ISO standards: ISO 14040 (2006), which

Table 1 Quantities of packaging components for each pallet configuration

	ex NZ			Repacked in Europe
Components per pallet	Modular bulk (MB)	International tray (IT)	Plateau single (P1)	Plateau single (P1)
Pallet base	1	1	1	1
Pallet card	1	1	1	1
Cardboard packs	100	232	145	145
Interconnecting strips	4	4	4	0
Corner boards	4	4	4	4
Cardboard top cap	1	1	1	1
Polybags/liners	100	232	145	0
Pocket packs	0	232	145	145
Strapping	5	5	5	5
EAN pack labels	100	232	145	145
Fruit labels/no. of fruit	9,100	7,656	7,540	7,540
Weight of kiwifruit (kg)	997.41	839.14	821.43	821.43

J. Clendon, Packaging Manager, Zespri International Ltd, personal communication, 12 February 2010

provides an overview of LCA, and ISO 14044 (2006), which gives more detailed guidance about undertaking an LCA study. The PAS 2050 (BSI 2008) also provided further methodological guidance.

The main impact category considered is climate change based on CML 2001—Nov 09, 100-year global warming potential (GWP). This is a carbon footprint; therefore, results do not reflect overall environmental performance. GaBi 4.4 was used to model each of the supply chains.

2.1 Assumptions

In undertaking this analysis, the following general assumptions have been made (unless otherwise stated):

- Electricity is assumed to be from the national grid mix of the relevant country.
- Shipping is by reefer ships and an emission factor of 0.024 kg CO_2e t/km (Wild 2008) has been applied.
- Pallet bases are assumed to be reused 50 times.
- EAN pack labels are assumed to enter the waste stream with the cardboard packs.
- Recycling processes for plastic and card have been modelled on generic processes in the GaBi 4.4 database in the absence of specific data.
- Recycled paper does not have the same quality as virgin paper due to wear and tear on the fibre during paper use and recovery. This study has conservatively assumed that 1 kg recycled paper substitutes for 0.5 kg virgin paper (Gaudreault and Vice 2011). This assumption is tested in the sensitivity analysis.
- Fruit is checked for quality and repacked at the port. Fruit loss at the port in Japan is estimated at 2.2 % for IT trays and 0.5 % for MB packaging, Fruit loss at the port in Zeebrugge is estimated at 2.0 % for all pack types entering the port. These assumptions are based on ZESPRI quality control information. Fruit loss varies due to a range of reasons and the impact of this is outside the scope of the study.

2.2 Omissions

Processes related to the fruit rather than the packaging were excluded, including fruit production and transport to packhouse, packing and refrigeration of fruit at the packhouse, repacking and warehousing of fruit once received at offshore ports, refrigeration energy during repackaging and storage, activities at distribution centres and activities at retail outlets. Fruit loss between the port and distributors/supermarkets is not included due to lack of available data. In Germany, very little or no packaging is taken home by the consumer and so has been deemed to be immaterial and not included. In Japan, fruit may be taken home by the consumer in plastic bags or clamshells; this transport is also excluded as there were no data available on how the packaging is transported. In both the German and Japan supply chains, the storage/repack facilities are directly adjacent to the port and transport emissions from port to storage/repack facility were deemed immaterial.

2.3 Life cycle inventory

Data for this analysis have come from a number of sources. Zespri has provided data on the packaging specifications as well as data on the processes they undertake, such as transport to export markets, and packaging disposal methods within their operations. The carbon footprint of each of the packaging

materials was calculated based on primary data from Zespri packaging manufacturers. Information on packaging disposal has been sourced directly from the market or country waste statistics. Input data for upstream processes such as raw material sourcing and downstream processes such as disposal have come from the LCA database GaBi 4.4. All data are for 2010 and all Zespri data are based on 2010 sales.

2.3.1 Manufacture of packaging components and their packaging

There are up to 11 packaging components that make up each assembled pallet (Table 1).The weight of input materials, transport distance and mode for each of the pallet configurations are given in Table 2. The cardboard products have a more complicated supply chain and are described in more detail in the following discussion.

2.4 Cardboard products

Board products are made up of a range of layers of paper manufactured at two sites. Details of the paper inputs, manufacturing, by-products, waste and packaging are provided in the following discussion for both paper manufacturing sites and a third pulp manufacturing site, and then detailed information on each of the board products is provided.

2.4.1 Paper production site 1

Paper at site 1 is manufactured using the materials listed in Table 3. There are a number of other inputs not listed as these

Table 2 New Zealand packaging material inputs per pallet, transport mode and distance

Packaging component	Material	Material weight (kg) per pallet	Transport mode	Transport distance (km) to manufacturer	Transport distance from manufacturer to packhouse (truck)
Pallet base	Kiln-dried timber	26.00	Truck	116	142
	Steel nails	0.05	Truck	464	
			Container ship	9,357	
Pallet card	Paper board	0.11	Truck	438	227
Strapping	Polypropylene	2.45	Truck Container ship	108 2,623	231
	Polycarbonate	0.08	Truck	47	
			Container ship	9,399	
Polybag/liner imported	PET film	MB 0.99 IT 0.88	Truck Container ship	50 9,656	20
		P1 0.99			
Polybag/liner NZ manufacture	HDPE granulate	MB 0.42 IT 0.38	Truck Container ship	1,030 10,969	100
		P1 0.42			
EAN pack labels	Glassine paper, wood-free paper, adhesive	MB 0.11 IT 0.26	Truck Container ship	15 2,975	227
		P1 0.17			
Fruit labels	Backing paper, PE film, adhesive	MB 0.43 IT 0.34	Truck Container ship	15 13,000	227
		P1 0.35			
Pocket pack	PET resin	IT – 5.57 P1 4.49	Truck Container ship	80 9,506	300
Cardboard pack	Cardboard	MB 48.0	Board products are manufactured at two sites from a number of different materials (see section 2.4)		418—ends, MB blanks
		IT 79.46			215—IT blanks
		P1 66.61			215—P1
Interconnecting strip	Cardboard	MB. 0.56 IT 0.16			418
		P1 0.56			
Corner boards	Cardboard	2.8			142
Top cap	Cardboard	1.15			215

Zespri packaging suppliers, personal communication, 19 February 2010 to 30 April 2010

Table 3 Material inputs for 1 t of paper used in the manufacture of cardboard packaging products at site 1

Material	Quantity (t)	Transport distance to manufacturer (km)	Transport mode
Logs	2.35	121 (average)	Truck
Wood chips	0.51	75 (average)	Truck
Recycled fibre	0.38	339 (average)	Truck
Pulp – from site 3	0.03	142	Truck
Burnt lime	0.009	155	Truck
Aluminium sulphate	0.027	97.5	Truck
Sodium bisulphite	0.009	0.2	Piped

Zespri cardboard supplier, personal communication, 26 March 2010

are minimal (0.9 % of total paper inputs) and have not been included in the analysis. The carbon enmissions associated with the production of logs and wood chip is based on McCullum (2009) and Sandilands (2009). Sodium bisulphite is manufactured at an adjacent plant and piped 200 m; no data were available on the energy requirement for this step and it has been excluded. Aluminium sulphate is manufactured from aluminium trihydrate (shipped 9,148 km, trucked 89 km to the manufacturing site) and sulphuric acid (trucked 89 km). These are then mixed with water and the aluminium sulphate trucked to the paper manufacturer. Sodium bisulphite is manufactured from sodium metabisulphite (shipped 10,773 km). GaBi inventory data for sodium sulphate have been used as data could not be sourced for sodium bisulphate. A small amount of pulp from site 3 is used (see Table 4). The pulp mill also has a number of other chemical inputs but these have been omitted as they contribute only 0.001 % to the site 1 paper inputs.

Energy use is summarised in Table 5, where energy used for extraction of by-product chemicals from the liquor stream was unable to be separated out due to lack of date. This may have resulted in slightly higher carbon footprint estimates for board products.

2.4.2 Site 2, recycled paper production

The transport of all paper inputs and all material and energy inputs (Table 6) required to manufacture the recycled paper are included in the carbon footprint. Waste paper is the main material used in the production of recycled paper with 1.21 t of waste paper (10–15 % moisture content) needed per tonne of recycled paper (7.5 % moisture content). A minimal amount of starch is also used in this process but has been excluded from this analysis due to the small contribution (<0.5 %).

Table 4 Material and energy inputs (per tonne pulp) for the production of pulp at site 3

Inputs	Amount	Unit
Logs and chips	4.58	t
Electricity—grid	1.34	GJ
Bioenergy	27.91	GJ
Steam—geothermal	6.98	GJ
Fossil fuels	2.87	GJ

Zespri cardboard supplier, personal communication, 26 March 2010

2.5 Cardboard packs

Each assembled pallet contains a different type and different number of cardboard packs. MB packs hold loose fruit (no pocket pack used), the IT pack is designed to hold a single layer of fruit in a pocket pack and the P1 holds a single layer of fruit in a pocket pack with higher strength cardboard. MB and IT cardboard packs consist of two components – *ends* and *blanks*. Both are made from a mix of paper from sites 1 and 2 (Table 7). P1 packs are made up of 86 % paper from site 1 and 14 % paper from site 2.

Blanks and ends are transported separately to the packhouse, on pallets wrapped in stretch film, where they are combined to make the packs (two ends, one blank per pack). Secondary packaging details are provided in Table 8. Interconnecting strips, corner boards and top caps are manufactured from cardboard made from a mix of paper from site 1 and site 2 (Table 9).

2.5.1 Transport of assembled pallets to export market retailer

Transport distances and mode from New Zealand for the two markets investigated are given in Table 10. The majority of fruit enters Japan through the port of Yokohama and is sold within Tokyo, so this is the transport route included in the analysis. In the German supply chain, fruit is trucked from Zeebrugge to markets

Table 5 Energy inputs at site 1

Inputs	Amount (GJ/tonne of paper)
Electricity from grid	2.02
Natural gas	6.19
Waste oil	0.13
Woodwaste	8.70
Black liquor	9.21
Diesel	0.05
Petrol	0.002
LPG	0.0007

Zespri cardboard supplier, personal communication, 26 March 2010

Table 6 Material and energy inputs in the manufacture of cardboard packaging at site 2 (per tonne of paper)

Inputs	Amount	Unit
Paper	1.21	t
Electricity—grid	1.81	GJ
Natural gas	0.12	GJ
Purchased steam (natural gas)	4.50	GJ
Diesel	0.05	GJ

Zespri cardboard supplier, personal communication, 26 March 2010

Table 8 Secondary packaging material, cardboard pack *ends* and *blanks*

Material	MB	IT	P1
Pallet	26.05	26.05	26.05
Stretch film wrap per pallet of blanks	0.476	0.222	
Stretch film wrap per pallet of ends/P1's	0.470	0.446	0.442
No. of blanks per pallet	885	1,060	
No. of ends/P1's per pallet	3,340	8,100	570

Zespri cardboard supplier, personal communication, 5 April 2010)

throughout Germany. Munich was chosen as a representative distance from the port.

2.5.2 New packaging in market

In both markets, some MB packs are repacked into new packaging and structural packaging is added throughout the supply chain. Tables 11 and 12 provide an overview of new packaging in the German and Japanese supply chains. In Germany, MBs that are repacked into P1s make up 10 % of the green kiwifruit market. In Japan, all MBs are repacked with the majority going into clamshells (69 %) and plastic bags (35 %), and additional cardboard boxes are required to pack them into.

2.5.3 Disposal

Three waste streams were considered within the system boundary of the carbon footprint:

- Waste following manufacture of components in New Zealand.
- Secondary packaging (i.e. component packaging). This has been omitted due to a lack of detail on how the packaging is disposed of.
- Disposal of the pallet components in the Japan and German markets at the repack warehouse, the distributors and/or transport company warehouses, and finally the retailer (Table 13).

3 Results

The total carbon footprint for packaging and delivery of kiwifruit from New Zealand to Munich, Germany, is in the range 0.65–0.67 kg CO_2e per kilogram of fruit delivered to the supermarket (Fig. 2). Shipping contributes significantly to the carbon footprint of all supply chains ranging from 0.55 to 0.57 kg CO_2e per kilogram of fruit delivered and 76–82 % of total emissions. Truck transport from Zeebrugge to the market is another significant (9 %) contributor to the carbon footprint in all three pack scenarios assessed. MB pallets repacked into P1 pallets at Zeebrugge have the highest carbon footprint as the introduction of new P1 packaging in the market contributes significantly (6 %). This pack type is approximately 10 % of the overall volume of green kiwifruit entering Germany. The MB pallet going directly to the supermarket has the lowest carbon footprint. The recycling rate in Germany is very high, and credit for both cardboard and plastic recycling reduces the overall carbon footprint by 3–7 %.

The total carbon footprint for packaging and delivery of kiwifruit to Tokyo, Japan, is in the range 0.33–0.40 kg CO_2e per kilogram of fruit delivered to stores (Fig. 3). Shipping contributes significantly to the carbon footprint of all supply

Table 7 Material details for pack *blank* and *end* manufacture (per blank/end)

Material, pack blank	Pack blank				Pack end			
	Quantity (g)		transport distance (km)	Transport mode	Quantity (g)		transport distance (km)	Transport mode
	MB	IT			MB	IT		
Site 1 paper	252.2	225.2	352 (MB), 212 (IT)	Truck	70.7	26.1	352	Truck
Site 2 paper	55.4	52.8	550 (MB), 7 (IT)	Truck	15.5	6.1	550	Truck

Zespri cardboard supplier, personal communication, 29 March 2010

Table 9 Material details for paper board manufacture (per interconnecting strip/corner board/top cap)

Material	Quantity (g)				Transport distance (km)	Transport mode
	Interconnecting strip		Corner board	Top caps		
	MB/P1	IT				
Site 1 paper	57.4	16.4	0.2	0.74	98	Truck
Site 2 paper	82.6	23.6	0.5	0.41	116	Truck

Zespri cardboard supplier, personal communication, 5 April 2010

chains ranging from 0.22 to 0.25 kg CO_2e per kilogram of fruit delivered and 58 to 71 % of total emissions. MB pallets repacked into four-piece clamshell have the highest carbon footprint at 0.40 kg CO_2e per kilogram of fruit delivered to stores. This relates to the cradle to repack contribution of the plastic clamshell (just over 21 % of the carbon footprint), the introduction of additional cardboard cartons at repacking (4 % of the total carbon footprint) and a low plastic recycling rate (22 %) in Japan. IT pallets going directly to the supermarket have the highest carbon footprint ex New Zealand but minimal additional packaging is added in Japan. The MB has a much lower carbon footprint than the IT ex New Zealand, and while emissions related to the plastic bag and the low plastic recycling rate adds significantly, MB pallets repacked into plastic bags have the lowest overall GWP (0.33 kg CO_2e per kilogram of fruit). The level of recycling in Japan means that there is no overall credit for plastic recycling (the credit received for recycling 22 % of the plastic is outweighed by the emissions from disposal of remaining plastic such as incineration and landfill). In contrast to Germany where recycling rates are high, plastic disposal in Japan is creating significant emissions, particularly relating to the clam shell. For plastics in Japan that are recycled, a significant proportion is done in China adding emissions from transporting baled waste to the overseas recycler. In the market, transport is low compared to Germany because only transport within Tokyo was considered. The carbon footprint would increase significantly if large volumes of fruit were trucked to any distance within Japan.

3.1 Sensitivity and scenario analysis

Four scenarios have been assessed for the German MB supply chain and one for the Japan MB supply chain. The German base case is the MB pallets direct to the supermarket in Munich, while the Japan base case is the MB pallet to four-piece clamshell and then the supermarket. The scenarios assessed were as follows:

Shipping emission factor Shipping of kiwifruit and packaging from Tauranga to Zeebrugge contributes the majority of emissions to the supply chain (85 %). The emission factor used in this study and in the base case was based on the scoping study of the kiwifruit supply chain at 0.024 kg CO_2e/t/km (Wild 2008, Mithraratne et al. 2010). There is a great deal of uncertainty around this value, although the reasons for the variation between published emission factors are not clear. Emission factors for refrigerated or reefer ships vary from 0.015 (DEFRA, 2011) to 0.024 (Mithraratne et al. 2010). The impact of reducing the shipping emission factor has been assessed assuming an emission factor of 0.017 kg CO_2e/t/km from Fitzgerald et al. (2011), and results show that this reduces emission estimates by 24 % (Fig. 4).

Table 10 Packed pallet transport distances to market

From	To	Distance (km)[a]	Mode
Packhouse in New Zealand	Port of Tauranga, New Zealand	22	Truck
Tauranga port	Yokohama, Tokyo port	8,917	Reefer ship
Yokohama port	Distribution centre	20	Truck
Distribution centre	Tokyo supermarket	40	Truck
Packhouse in New Zealand	Port of Tauranga, New Zealand	22	Truck
Tauranga port to	Zeebrugge, Belgium port	20,823	Reefer ship
Zeebrugge to	Munich service provider	897	Truck
Munich service provider	Supermarket distribution centre	10	Truck
Supermarket DC	Munich supermarket	10	Truck

[a] Road transport distances are based on Google Maps (2009), and shipping distances are based on Portworld (2009)

Table 11 German supply chain, new packaging for one pallet (kg)

New packaging material	MB, P1 ex NZ	P1 repacked from MB
Strapping—polypropylene	2.75	5.3
Pocket pack—polypropylene		4.65
Stretch film, linear low-density polyethylene	2.52	2.52
Cardboard pack		69.22
Cardboard top cap and corner boards	7.11	7.11
Europal wood base	0.35	0.35

W de Rooij, Assistant Operations Manager Europe, Zespri International Ltd, personal communication, 23 June 2011

Paper substitution Recycled paper and virgin paper do not have the same quality or functionality. As fibres are reused, they become too short to be of further use in papermaking and can no longer be retained in the pulp slurry within the processing system. Hence, longer fibres (virgin) have to be added into the papermaking system to retain quality. The base case has assumed that recycled paper substitutes for virgin paper at a 1:0.5 ratio, and the impact of a 1:0.8 ratio is shown in Fig. 4. Changing this ratio reduces the supply chain carbon footprint by about 1 % from the base case. It is unknown what ratio of virgin to recycled paper is actually used by the various recyclers across the supply chain.

Local recycling The base case assumes that plastic and board materials are sent to China and hard coal was used to provide electricity for recycling products. The impact of recycling locally in Germany assuming a transport distance of 200 km and the use of grid electricity in Germany is assessed. This is shown in Fig. 4 with a less than 1 % reduction in the carbon footprint from the base case.

Rail transport Road transport of the kiwifruit and packaging from Zeebrugge to Munich contributes about 9 % of the carbon footprint. This scenario assesses the impact of transporting the fruit using diesel cargo trains, and results show that this could reduce the carbon footprint by 5 % (Fig. 4).

MB trays direct to retailer in Tokyo MB packs are all repacked into additional packaging in Tokyo, while in Germany most MBs are sent directly to the supermarket with no additional packaging. This scenario looks at the impact of sending the MB packs directly to the retailer in Tokyo. This results in a 30 % reduction in carbon footprint compared with the use of clamshells (Fig. 4). The reduction is mainly due to the reduced need for manufacture of the thermoformed polystyrene clamshell itself (20 % reduction). The reduction in cardboard boxes required to pack the clamshells into reduces the footprint by 4 %, largely due to the cardboard manufacture. The clamshells are manufactured 617 km away and the cardboard boxes 40 km away, but transport of the additional packaging does not contribute significantly. The remaining 6 % reduction from clamshell substitution is due to no incineration of the clamshells at end of life, although there is also a credit for the recycling of cardboard at end of life.

4 Discussion

Shipping is a major contributor to the kiwifruit carbon footprint as shown in this and previous studies (Mithraratne et al. 2010). There is some uncertainty around how shipping emissions are calculated as demonstrated by the wide range of carbon emission factors available in the literature. This study has used a very conservative emission factor, so it is possible that the shipping carbon footprint is an overestimate as shown by the sensitivity analysis. Zespri is working with shipping partners to address the shipping emissions uncertainty and reduce the emissions where possible.

Other areas of the supply chain are under direct Zespri control and may be easier to change. Opportunities to reduce emissions in the German supply chain include the following:

- Reduction in the use of P1 repacked from MBs at Zeebrugge. This supply chain has the highest carbon

Table 12 Japan supply chain, new packaging for one pallet (kg)

New packaging material	MB into clamshells	MB into plastic bags
Strapping—polypropylene	1.53	1.53
Stretch film, linear low density polyethylene	0.52	0.52
Cardboard pack	61.15	61.15
Clamshell—polystyrene sheet[a]	19.91	
Plastic bags—low density polyethylene an d polypropylene		7.09

OLy, Assistant Operations Manager, Tokyo, Japan, Zespri International Ltd, personal communication, 26 May 2011

[a] Used the Gabi Process, polystyrene part, Plastics Europe

Table 13 German and Japanese packaging disposal (%)

	Germany repack[a]	Germany, service provider	Germany retailer	Japan
Cardboard—recycled	100	99	100	79[b]
Incinerated with energy recovery		<1		21
Plastics—recycled				
All	100	85		22
Strapping/pocket pack			92	
Bags/liners/stretch film			100	
Plastics—Incinerated, energy recovery—incinerated, no energy recovery—landfill		8 7	8, strapping/pocket pack	49[c] 11 10
Other				8
Wooden pallet—recycled				38[d]
Incineration with energy recovery				21
Incineration, no energy recovery	100			24
Compost				10
Other				7

[a] Zespri Waste Contractors

[b] Paper Recycling Promotion Centre 2009

[c] Plastic Waste Management Institute, Japan 2011

[d] PE Asia, personnal communication, 19 May 2011

footprint due to the additional packaging used during the repack and makes up to 10 % of the market.

- Increasing the use of MBs direct to the supermarket as this has the lowest carbon footprint.

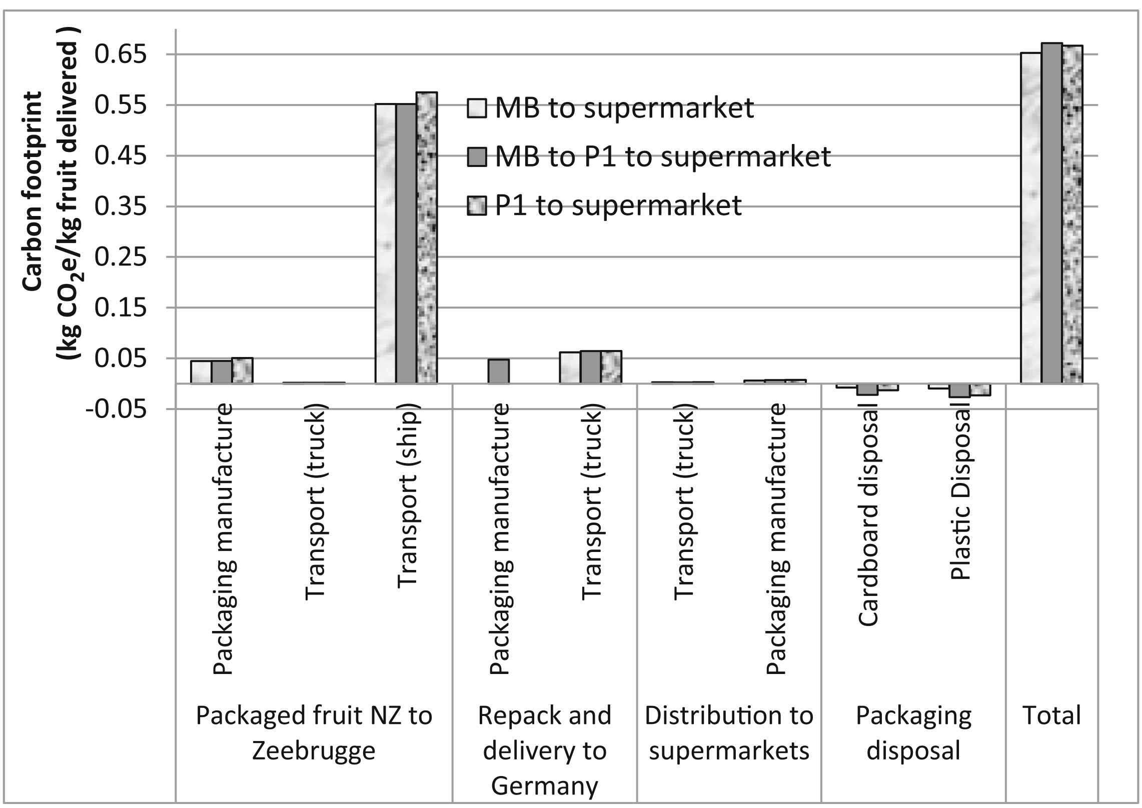

Fig. 2 Carbon footprint of New Zealand kiwifruit packaging and transport to Munich, Germany

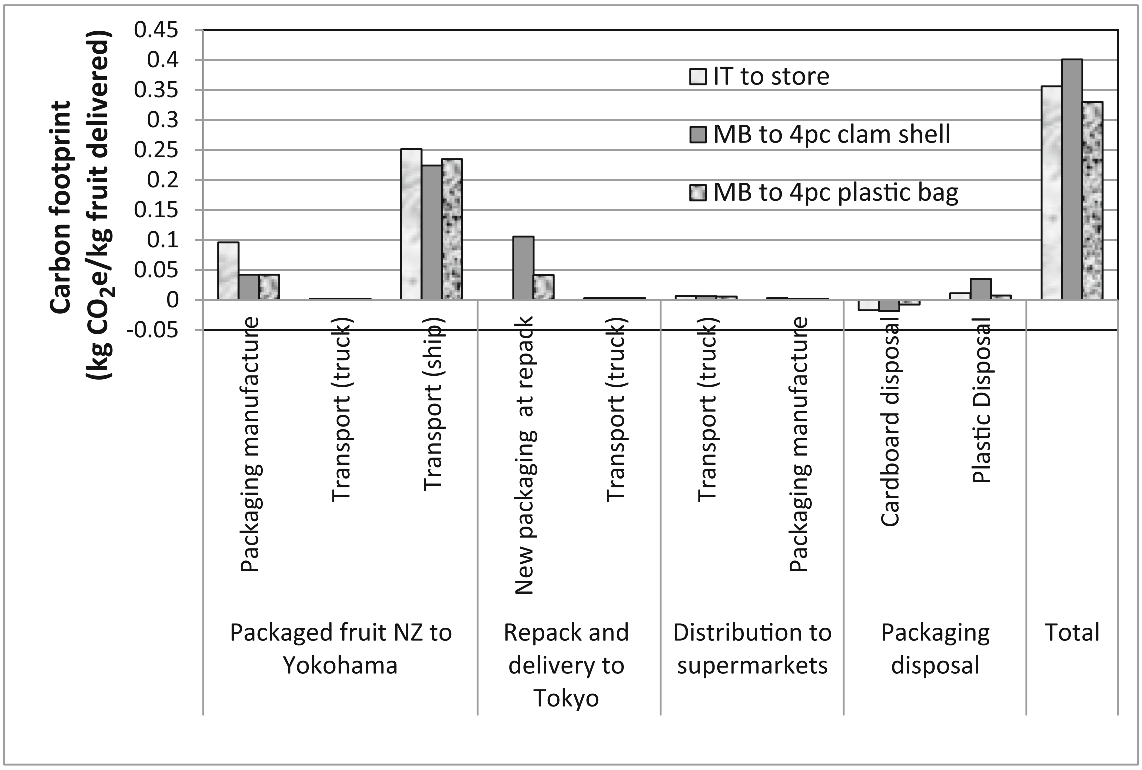

Fig. 3 Carbon footprint of New Zealand kiwifruit packaging and transport to a retailer in Tokyo Japan

- Increasing the local recycling of material rather than shipping it offshore.
- Reduction of the in-market transport carbon footprint (e.g. assessing the use of rail transport).

Opportunities identified to reduce the carbon footprint of the Japanese supply chains are as follows:

- Reduce the use of clamshells and use plastic bags instead.

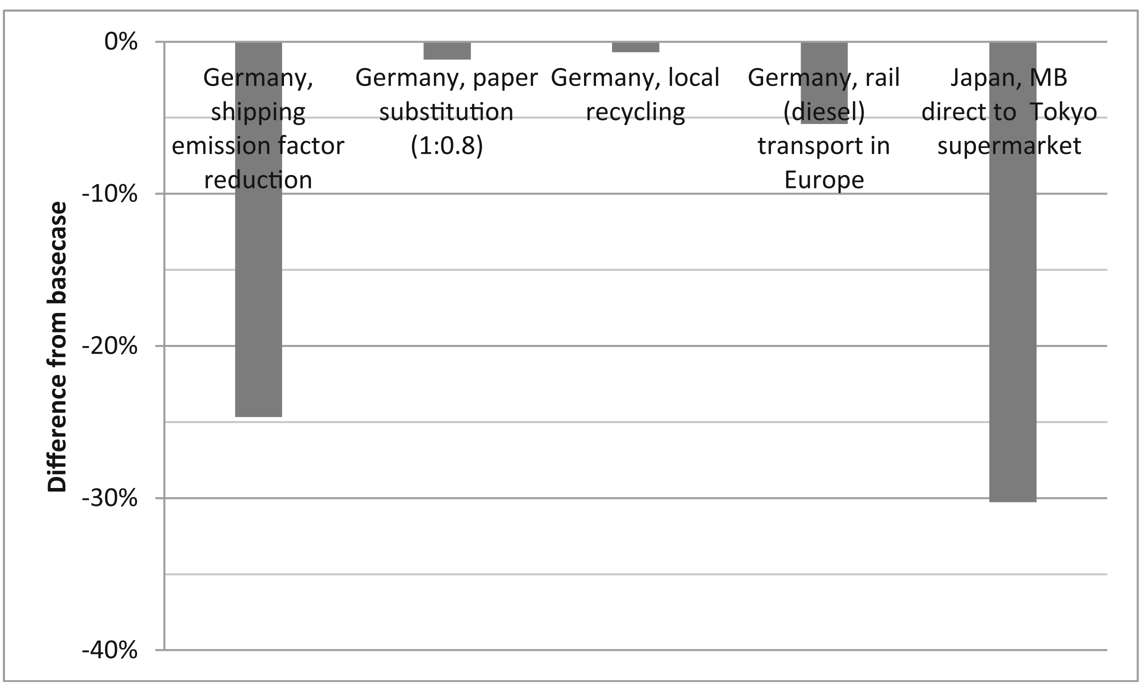

Fig. 4 Sensitivity and scenario analysis results

- Work with partners in the supply chain to increase both the plastic packaging recycling rates and access to data on recycling of plastic.
- An option that may be outside of Zespri control would be to encourage the use of MBs direct to the supermarket and the use of reusable bags by consumers to take fruit home as is done in Germany; this could reduce the carbon footprint by up to 30 % compared to the use of clamshells.

Comparing these results to the packaging results in the scoping study by Mithraratne et al. (2010) is problematic. This was not the aim of the study and the system boundaries and functional unit are different between the two studies. Both studies indicate that shipping is a significant contributor to the carbon footprint.

Adjusting the Mithraratne et al. (2010) packaging results to the same functional unit of 1 kg of fruit, produces a carbon footprint for packaging (IT packs) of 0.012 kg CO_2e (calculated from Mithraratne et al. (2010) as the packhouse carbon footprint (0.464 kg CO_2e)/fruit weight in one tray (3.3 kg)*packaging % of carbon footprint (12 %)−packaging footprint attributed to fruit waste (30 %)) compared with 0.093 kg CO_2e in this study (IT, packaging only, excluding transport emissions). This is due to differences in the following:

- Raw data with regard to how much of each packaging type is used—Mithraratne et al. (2010) has a packaging weight of 0.38 kg/IT pack, while this study has a packaging weight per IT pack of 0.51 kg. This is a 33 % increase and is due to a heavier cardboard box and inclusion of a pallet card, cardboard strips between boxes and a cardboard cap that goes on top of a packed pallet of fruit.
- Cardboard emission factor—Mithraratne et al. (2010) uses an emission factor of −0.212 kg CO_2e/kg and assumes that the cardboard is from a plantation forest that is a carbon sink. This study assumes that the cardboard comes from a sustainably managed forest that is not a carbon sink and has a carbon footprint of 0.54 kg CO_2e/kg cardboard, although the cardboard also generates a carbon reduction at end of life of 0.05 kg CO_2/kg.

5 Conclusions

The carbon footprint of kiwifruit packaging and transport to market varies considerably due to distance to market. Other areas of the supply chain that have an impact on the footprint include the packaging configuration, land transport, additional in market packaging and recycling rates. There are a range of options for capturing reductions in the carbon footprint of the New Zealand kiwifruit packaging and transport supply chain. Initiatives that could have the most impact on the carbon footprint include increased efficiency in shipping, use of trains for land transport, managing the packaging type to minimize those supply chains with a higher carbon footprint and replacing the use of polystyrene clamshells with alternative materials or plastic bags.

Other options will tend to be incremental (i.e. a number of small gains) and would involve working closely with partners in the supply chain. These options include identifying alternative material for components of the packaging, reductions in the addition of structural packaging in market, identifying alternative material for components of the packaging and maximizing recycling rates along all stages of the supply chain.

The carbon footprint does not reflect all environmental impacts, and to avoid burden shifting, all relevant environmental impacts should be considered in decision-making with regards to the kiwifruit packaging and transport supply chain.

Acknowledgments This study was funded by Zespri International Ltd. Our thanks go to Alistair Mowat at Zespri for his constructive feedback throughout the project. Glen Arrowsmith and Janet Clendon at Zespri provided us with information on supply chains and packaging specifications. Zespri packaging suppliers and upstream supply chain businesses were great at providing data. We also appreciate the advice received from Babara Nebel and David Drysdale at PE Australasia.

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